SELF-ADHERENT UNDERWRAP MAINTAINS RANGE OF MOTION RESTRICTION AFTER EXERCISE

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DEDICATION

I dedicate my Masters thesis to my three best friends Sarah Joy Brown, JoBeth Taylor (McGinty), and Mandy Nash. These ladies are all living in different parts of the country but were always available for lengthy phone discussions about life's crazy situations over the past two years. I would not have made it through without each and every one of them and feel blessed to have such great friends. Thank you ladies!

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Richelle VanWagoner

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The use of athletic tape to decrease ankle range of motion and aid in the prevention of lateral ankle injuries is widespread and has been extensively researched. Various forms of underwrap are often used with taping to allow for better protection of the underlying skin. A lack of research exists concerning the best form of underwrap that should be used with taping to aid in the restriction of ankle range of motion. The purpose of this study is to assess the effectiveness of different underwrap conditions on reducing ankle range of motion before and after exercise. Twenty subjects were used in this study (11 male, 9 female, 20.75±1.48 yrs, 175.29±9.24 cm, 74.39±11.77 kg). Subjects were physically active with no history of lower extremity surgery or recent injury as well as no history of any serious medical condition. Four conditions were evaluated: 1) a control (no tape or underwrap), 2) tape applied directly to the skin, 3) tape applied to foam underwrap, and 4) tape applied to self-adherent underwrap. An ankle electrogoniometer was used to measure ankle range of motion in two planes, inversion to eversion and dorsiflexion to plantarflexion in degrees. Subjects came to the laboratory four separate days, one for each condition being tested. Ankle range of motion was measured initially before tape application (pre-tape) and again after tape application (post-tape). Subjects then performed a thirty-minute exercise regimen consisting of a five-minute warm-up, twenty minutes of drills involving multi-directional movements and ending with a five-minute cool down. Ankle range of motion was measured again after the exercise protocol (post-exc).

Two different repeated measures Analysis of Variance (RMANOVA) were performed to establish the differences in ankle range of motion restriction between the tape conditions, one for

each direction. Tukey's post-hoc analysis was done on all significant findings. The statistical analysis identified a significant tape condition by time interaction for the inversion-eversion range ($F_{6,114}$=33.20, p=.001) and the dorsiflexion-plantarflexion range ($F_{6,114}$=54.96, p=.001). Furthermore, all the post-tape measures and post-exercise measures were significantly different from the pre-tape measures. Analysis of inversion-eversion revealed a significant loosening after exercise in both the tape to foam and tape to skin conditions. However, no significant loosening occurred in the tape to self-adherent condition. Analysis of dorsiflexion-plantarflexion revealed a significant loosening after exercise in only the tape to skin condition. These findings indicate tape to self-adherent underwrap maintains its inversion-eversion range of motion restriction after exercise. Tape to self-adherent underwrap and tape to foam underwrap maintains its dorsiflexion-plantarflexion restriction after exercise.

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INTRODUCTION

The most common injury suffered by individuals who participate in athletics is the lateral ankle sprain.[1-10] Sports involving quick changes in direction and multi-directional movements typically have the highest incidence of ankle sprains.[11,12] The most likely mechanism of injury for lateral ankle sprains is an excessive inversion force usually involving plantarflexion and internal rotation.[2,13,14] The cause behind this excessive force varies, but typically occurs from landing or stepping on irregular surfaces, equipment, another athlete, or a quick change of direction.[2]

Due to the common occurrence of ankle sprains, the use of athletic tape as a preventative measure has been popular.[5,15-17] Athletic tape has been shown to be effective in reducing the number and severity of ankle sprains.[15,17] One study reported that with ankles taped for all sports activities the chance of an ankle sprain decreases by at least 50%.[16] Karlsson et al.[5] stated that tape was effective for three primary reasons: decreasing mechanical ankle instability, limiting the extremes of ankle motion, and increasing proprioceptive capabilities. One study[18] interviewed athletes to determine their reasoning behind getting their ankle taped. Athletes reported they got their ankles taped because they felt the tape increased their confidence, increased their ankle strength, or decreased their concern for injury/re-injury.[18]

Multiple studies specifically investigated the effects of ankle taping on limiting range of motion.[1,3-6,8-10,15,17,19-30] Most of these studies have found range of motion was significantly decreased in all directions immediately after tape application, but especially in the inversion and plantarflexion directions.[1,3-5,8,9,17,20,22,24,26,31] In fact, a recent study demonstrated a 62% decrease

in ankle inversion range of motion immediately after tape application.[20] However, many of these same studies have also reported this taping to loosen with exercise.[1,3,4,6,8-11,19,23,24,26,28-32]

Previous authors have stated that loosening of tape may be attributed to moisture accumulation due to sweat,[15] excess extensibility of the ankle connective tissue,[26] method of skin preparation,[29] inequality of the skin due to muscle contraction,[15] and/or improper tape application.[26] Underwrap could also be a contributing factor to tape loosening. Underwrap or prewrap is often used with taping to reduce friction and irritation to the skin.[5,9,11,15] Foam underwrap has been commonly used prior to tape application, but recently a self-adherent prewrap has been developed as a new form of underwrap. One study identified self-adherent prewrap as a possible contributor in maintaining range of motion restriction following exercise.[9] This study reported self-adherent prewrap had additional tensile strength and moisture restraint capabilities not found in other forms of underwrap.[9]

In general, little research exists on the effects varying underwrap conditions may have on ankle range of motion. Results vary among these studies.[10,11,15,26,28] Two investigations concluded underwrap caused decreased range of motion restriction when compared to tape to skin conditions,[10,28] only one found no difference in range of motion restriction capabilities,[26] and one found the use of underwrap facilitated greater range of motion restriction compared with tape to skin conditions.[15] Lastly, another study[11] also found no difference between tape to skin versus tape to prewrap but instead of measuring range of motion restriction they evaluated active and passive resistance to inversion. This limited number of investigations did, however, reach one consensus. All found that regardless of the type of underwrap used, restrictive capabilities of ankle taping are lessened with exercise.[10,11,15,26,28]

Many investigators examine the effects of exercise with ankle taping and range of motion restriction; [1,3,4,6,8-11,19,23,24,26,28-32] most report the use of a foam underwrap but fail to elaborate further on its' specific role in the ankle taping.[4,8,9,11,17,22,30,33] No research has been performed on the use of self-adherent prewrap with white cloth tape and its' effects on ankle range of motion restriction before and after exercise. Therefore, the purpose of this study is to assess the effectiveness of different underwrap conditions on reducing ankle range of motion before and after exercise.

METHODS

Subjects

We started with twenty-eight subjects, two did not meet the inclusion/exclusion criteria and six subjects dropped out due to discomfort caused when exercising with the tapings. Twenty physically active individuals were tested for this study (11 male, 9 female, 20.8±1.5 yrs, 175.3±9.2 cm, 74.4±11.8 kg). Subjects were considered physically active if they exercised approximately three times per week for at least thirty minutes. Subjects were volunteers from classes in the School of Health, Physical Education, and Recreation. Individuals showing any signs or symptoms of a current lateral ankle sprain (swelling, ecchymosis, altered gait) were excluded from the study. But, subjects with a history of ankle sprain at least six months prior were included (n=13). These subjects tended to have excess range of motion that may have contributed to the higher mean ranges found in Table 1. Additionally, subjects with a previous history lower extremity surgery, any heart condition, or any serious medical conditions were also excluded. Serious medical conditions included, but were not limited to, diabetes, neurological/sensory deficit, and severe asthma. Only the right ankle was taped and tested for this study in order to remain consistent with previous literature and day-to-day measurements.

Upon arrival subjects were asked to shave and thoroughly clean the ankle if not done previously. Before participating in the study, all subjects read and signed an informed consent form approved by the University's Institutional Review Board for the Protection of Human Subjects, which also approved this study.

Instrumentation

An ankle electrogoniometer (Figure 1) was used to measure ankle range of motion, in degrees, in two planes of motion. This piece of equipment has been used in previous research.[9,23,34,35] The reliability of the device has been established as excellent with an ICC = .90.[9] Other items used in this study included: 1 ½ inch wide, white cloth athletic tape (Johnson and Johnson Zonas®, Skillman, NJ), foam underwrap (Mueller®, Prairie Du Sac, WI), self-adherent underwrap (Andover PowerFlex™, Andover, Salisbury, MA), adhesive spray (Super Tape Adherent, San Antonio, TX), and heel and lace pads (Mueller®, Prairie Du Sac, WI).

Procedures

Subjects came to the Athletic Training research laboratory on four different days, one for each condition. The average time between test sessions was 10.3 ± 7.9 days. All subjects completed each condition on a separate day. Tape conditions included: 1) control, (C) (no tape or underwrap), 2) tape applied directly to the skin, (TS) 3) tape applied to foam underwrap, (TF) and 4) tape applied to self-adherent underwrap (TSA). The order of testing condition was counterbalanced for all subjects. Subjects' ankle range of motion was measured before tape application and immediately after tape application. Subjects then went through a thirty-minute exercise protocol. Afterwards their ankle range of motion was measured a third and final time. Two mechanical ranges of motion were measured: dorsiflexion to plantarflexion range (˚) and inversion to eversion range (˚).

Range of Motion Testing

For range of motion testing, the subject was supine on the exam table. The knee was extended and the lower leg was strapped down using two hook-and-loop fasteners to prevent motion at the knee. The thighs were also strapped to the table to prevent motion at the hip. However, the larger mean ranges found in Table 1 may be attributed to lack of sufficient stabilization at the hip. While subjects' thighs were strapped to the table some accessory motion, internal and external hip rotation, was possible. Subjects did not wear shoes or socks during range of motion testing to remain consistent with previous studies.[9] A mechanical zero, or neutral, was established on the ankle goniometer. The subject was then instructed to move the ankle maximally through the full dorsiflexion-plantarflexion range. Next the subjects were instructed to move the ankle maximally through the full inversion-eversion range. Three practice trials were performed followed by three test trials for each of the two ranges. The mean of three test trials were used for statistical analysis.

Taping conditions

The subject was positioned on a treatment table for taping. For all taping conditions the subject's right ankle was placed in maximal dorsiflexion and the subject was asked to maintain this position for the duration of the taping application. The same examiner performed all taping.

For the tape to skin condition adhesive was sprayed over the ankle joint for approximately 3 seconds and allowed to dry for approximately 3 seconds. Heel and lace friction pads were then placed on the instep and achilles area. A closed basket-weave technique was applied. Using white cloth tape, the following was performed: 1) two anchor strips at the base of the calf muscle, 2) one anchor strip around the arch of the foot, 3) three stirrups starting medially

and moving laterally, 4) circular strips, down the lower leg to cover both malleoli, 5) two heel locks applied to the medial aspect of ankle, 6) two heel locks applied to the lateral aspect of the ankle, 7) figure-8, 8) one anchor strip around the arch of the foot, and 9) circular anchor strips moving up the lower leg.[36]

For the tape to foam underwrap condition adhesive spray was applied in the same manner as the tape to skin condition. Heel and lace pads were placed on the ankle. Foam underwrap was then applied starting with a figure-8, followed by medial and lateral heel locks, and finishing in a circular pattern up the lower leg overlapping by half and ending at the base of the calf. The primary investigator applied the closed basket-weave taping technique to the foam underwrap in the same manner as previously described. The white tape was not in contact with the skin, only the foam underwrap.

Finally, for the tape to self-adherent underwrap condition heel and lace pads were placed on the ankle, no spray adhesive was used based on manufactures directions. Self-adherent underwrap was applied by removing all the stretch to allow for maximum tension, also per manufacturers guidelines. It was then applied in the same manner as the foam underwrap. When finished, it was compressed to help conform to the ankle joint, per manufacturer's instructions. The primary investigator then applied the closed basket-weave taping technique to the self-adherent underwrap in the same manner as previously described. The white tape was not in contact with the skin, only the self-adherent underwrap.

Exercise protocol

After the tape condition was applied and ankle range of motion was measured, subjects completed an exercise regimen lasting thirty minutes. The examiner first walked through the

routine with the subject and explained the various drills. Next, subjects followed the examiner through the entire routine and performed each station along with the examiner. This counted as the warm-up and lasted for about five minutes. The exercise stations included: forward jogging, back-peddling, lateral shuffling to the left and right, a figure-eight, drills with the agility ladder, forward jogging and shuffling with 90 degree changes in direction, twenty wall-jumps, forward running with jumping over cones, and a zig-zag jog (Figure 2). These exercises were chosen due to the stress they placed on the ankle and their use in previous research.[4,9,37,38] The subject was asked to perform each station at a moderate level of physical exertion. The talk test was used to verify subjects were performing at a moderate level. Subjects were instructed that they should be able to talk briefly during the exercise protocol, but not in complete sentences. After twenty minutes the subjects ceased exercise and the primary investigator recorded the number of stations completed, the average number was 8.76 ± 1.25 rounds. Lastly, the subjects finished with a five-minute walk to cool down. The entire protocol included a total of thirty minutes of exercise.

Statistical Analysis

Two different repeated measures Analysis of Variance (RMANOVA) were performed to establish the differences between the tape conditions: one for the inversion-eversion range (INV_EV) and one for the dorsiflexion-plantarflexion range (DF_PF). The RMANOVA included two within subject factors: time at three levels (before tape application [Pre-Tape], after tape application [Post-Tape], and after exercise [Post-Exc]) and tape condition at four levels (control [C], tape to skin [TS], tape to foam underwrap [TF], tape to self-adherent underwrap [TSA]). The priori alpha level was set at $p < 0.05$. Tukey's HSD post hoc analysis was performed on any significant findings.

RESULTS

Means and standard deviations for ankle range of motion for all tape conditions are provided in Tables 1 and 2. We identified a significant tape condition by time interaction for the INV_EV ($F_{6,114}$=33.20, p=.001) and DF_PF ($F_{6,114}$=54.96, p=.001) ranges of motion. Results of Tukey post hoc analysis for each range of motion are described in great detail below.

Inversion-Eversion

For the TSA condition, we found a statistically significant difference between the Pre-Tape and Post-Tape conditions, but no difference between the Post-Tape and Post-Exc comparison. This identified a reduction in range of motion immediately after tape application and the reduced range of motion was maintained even with exercise. Conversely, the TF and TS had a significant difference between Pre-Tape and Post-Tape conditions, but also had a significant difference between Post-Tape and Post-Exc conditions. This would indicate that although both TS and TF initially reduced range of motion, a significant amount but loosening occurred after exercise. Furthermore, the TF and TS Post-Exc measures were significantly different from the TSA at the Post-Exc measure, with TSA maintaining inversion to eversion motion restriction (Figure 3).

A significant main effect was identified for tape condition ($F_{3,57}$=35.86, p=.001). The Tukey post hoc analysis found that overall the three different taping conditions restricted inversion-eversion range of motion as compared to the no tape condition, with the TSA condition restricting the most (46.82°±2.67°) followed by TS (49.29°±2.64°) and lastly TF (49.74°±2.60°).

Dorsiflexion-Plantarflexion

In the TSA and TF conditions we found a significant difference between the Pre-Tape and Post-Tape conditions, and no differences between the Post-Tape to Post-Exc comparisons. This again identifies a reduction in range of motion immediately after tape application and the reduced range of motion was maintained even with exercise. However, in the TS condition, we identified significant difference between Pre-Tape and Post-Tape conditions, but also had a significant amount of loosening between Post-Tape and Post-Exc conditions. Furthermore, the TF and TS Post-Exc measures were significantly different from the TSA Post-Exc measure with TSA restricting significantly more range of motion than the other two tape conditions (Figure 4).

A significant main effect was identified for tape condition ($F_{3,57}$=60.28, p=.001). Tukey post hoc analysis found that overall the three different taping conditions restricted a significant amount of range of motion as compared to the no tape condition. The TSA condition restricted the most dorsiflexion-plantarflexion range of motion (47.25°±1.60°). The TF (49.93°±1.89°) and TS (48.50°±1.81°) conditions restricted similar amounts of range of motion, but neither restricted as much range of motion as the TSA condition.

DISCUSSION

The use of prophylactic ankle taping has long been used to prevent ankle sprains or potentially decrease the severity of sprain if they do occur. [1,5,17,20,25,29,30] This prevention of injury occurs in part, by restricting excess range of motion at the ankle. Many studies have shown tape loosens with exercise, but most argue that even with loosening, tape is still able to restrict range of motion and prevent injury. [1,3,6,8,17,25,26,28,30,39,40] Limited attention has been paid to the role of underwrap in reducing range of motion at the ankle, especially the use of self-adherent underwrap.[9-11,15,26,28] Results of the current study identify that self-adherent underwrap assists in maintaining range of motion restriction after exercise.

The primary finding of the inversion-eversion analysis was that the tape to self-adherent underwrap condition restricted 32% of motion initially and maintained 95% of the restriction after exercise. The tape to foam and tape to skin applications performed similarly to each other. The tape to foam application restricted 33% of motion initially and maintained 75% of restriction after exercise and the tape to skin application restricted 34% initially and maintained 70% of restriction after exercise. The primary finding of the dorsiflexion-plantarflexion analysis was that the tape to self-adherent underwrap condition restricted 24% of motion initially and maintained 100% of restriction after exercise. The tape to foam underwrap condition only restricted 15% of motion initially but maintained 88%, while the tape to skin application restricted 23% of motion initially but only maintained 69% of restriction after exercise. So even with the greater loosening in the tape to skin condition, at the end of the exercise protocol it still restricted more range of motion than the tape to foam underwrap condition. The tape to self-adherent underwrap application restricted the most motion of all conditions for the inversion-eversion range. More importantly, it was the best at maintaining range of motion restriction after exercise.

When comparing our findings to previous literature differences and similarities were noted. A previous study[9] compared the use of self-adherent underwrap and self-adherent tape to a white tape with foam underwrap condition. In their investigation the self-adherent tape application restricted 25% of inversion-eversion range of motion and maintained 57% of restricted motion after exercise.[9] Their white tape to foam underwrap application restricted 13% of motion but maintained less than 1% of inversion eversion motion after exercise.[9] For the dorsiflexion-plantarflexion range the self-adherent tape application restricted 25% of motion and 59% of restricted motion was maintained after exercise.[9] Their tape to foam underwrap

condition restricted 18% of motion and maintained 67% after exercise. These findings suggest that the use of self-adherent materials, underwrap and tape, work to maintain range of motion restriction after exercise but potentially, not as well as our white tape to self-adherent underwrap application. While the use of both self-adherent tape and underwrap worked to maintain range of motion restriction after exercise, the use of white tape to self-adherent underwrap maintained 95-100% of motion after exercise. Therefore, use of self-adherent underwrap and white tape appears to increase the efficacy of white tape by acting as a moisture/sweat barrier between the skin and the white tape. Self-adherent underwrap may also add tensile strength to the tape application, especially in comparison to foam underwrap. Purcell et al.[9] indicated that self-adherent underwrap by itself adds up to 23lbs of tensile strength. Range of motion measurement procedures and exercise protocol by Purcell et al.[9] were similar to ours.

Delacerda[15] also had similar findings, he found that tape conditions using underwrap, either gauze or foam, significantly restricted more range of motion than tape to skin conditions. Our findings agree with this for the dorsiflexion-plantarflexion range, tape to skin loosened and tape to foam did not. But, in the inversion-eversion direction both tape to foam and tape to skin maintained the same amount of restriction. Both studies proved that tape to skin loosened more with exercise than tape to foam underwrap. The tape to skin conditions typically ripped and did not maintain range of motion restriction after exercise as efficiently as the conditions using underwrap.[15] The conditions using underwrap did not tear and subjects' did not complain of abrasions and blisters which occurred with the tape to skin condition.[15] It has been previously suggested that taping to skin allows for greater range of motion restriction.[10,28] Previous literature has also used tape to skin applications in their methods but did not compare it to different underwrap conditions, instead they compared tape to skin applications to ankle braces,[23]

different taping methods,[38] different types of tape,[19] or no tape conditions.[6,29] This rationale suggests that taping directly to the skin reduces the chances of the tape to slip. However, our findings, suggest underwrap may act to absorb sweat or prevent it from reaching the white tape, which allows range of motion restriction to be maintained. Thus, the use of underwrap actually aids in the effectiveness of white tape to reduce range of motion.

By using underwrap the white tape is less likely to rip, ripping causes the restrictive effect of white tape to diminish. Taping with any form of underwrap is more comfortable to the athlete, which will allow for better compliance with those whom need their ankle(s) taped. The tape to skin application restricted more motion originally but loosened notably with the 30-minute exercise routine. We can assume that with continued exercise the tape to skin condition would continue to loosen and eventually restrict less motion than the tape to foam condition. The use of foam underwrap did not restrict as much motion initially or after exercise as the other two applications, but it did not loosen with exercise like the tape to skin condition. However, self-adherent underwrap provides the most range of motion restriction both before and after exercise.

Two studies concluded tape to skin worked better than tape to underwrap to restrict range of motion both before and after exercise.[10,28] While these studies conflict with our findings we can identify specific methodological reasons for the differences. One of the investigations stated tape to foam underwrap did not limit inversion as well as tape to skin, however, they did not use adhesive spray.[28] The use of adhesive spray allows the foam underwrap to adhere directly to the underlying skin, lessening the chance of the tape application slipping or loosening. Our study used foam underwrap with adhesive spray, which is typically used clinically.

Limitations

There were a few limitations associated with this study. The exercise routine was only thirty minutes long, which does not compare to a typical practice or game session. Previous research is inconsistent on the amount of time subjects exercised before having their motion measured again. Studies have used five minutes,[10] twenty minutes,[9,29] forty minutes,[11] two hours of practice,[15] or measured at different intervals throughout an exercise routine or practice session.[3,23,30] Ricard et al.[26] had subjects run on a treadmill for ten minutes followed by figure-8 and shuttle runs and ending with bilateral toe raises. Our routine was similar in that it involved several change of direction drills and jogging, a treadmill was not used.

During our exercise routine several subjects complained of pain in their ankle or calf, and 6 even had to drop out of the study. Most complaints occurred with the tape to self-adherent underwrap and tape to skin applications. Four subjects' reported the self-adherent underwrap taping was too tight around their achilles tendon and the lower calf. Complaints also occurred during the tape to skin application with two subjects' stating the adhesiveness of the tape was pulling and irritating the underlying skin. Also, subjects complained of pain when removing the tape to skin condition.

Future Research

Future studies should compare alternate taping methods as well as various ankle braces to the use of self-adherent underwrap and white tape. Ankle braces may be tightened during activity to help maintain decreased range of motion. Also, the properties of self-adherent underwrap need to be investigated thoroughly. These include but are not limited to tensile strength and stretch

capabilities as well as its ability to oppose moisture (sweat). The use of self-adherent underwrap and white tape should be evaluated in athletic practices and competition settings as well.

Clinical Applications

Our study found all three taping conditions to significantly restrict range of motion immediately after application and after exercise. This solidifies the overall use of ankle taping to decrease range of motion. The use of self-adherent underwrap when taping an ankle, allows for greater range of motion restriction and it maintains that restriction after exercise, for both inversion-eversion and dorsiflexion-plantarflexion ranges. The tape to skin conditions typically ripped, was uncomfortable, and irritated the underlying skin. While tape to skin applications may restrict more range of motion initially, it noticeably loosens with exercise. Self-adherent underwrap does not loosen with exercise and thus maintains the motion restricted allowing for a better chance of injury prevention. In conclusion, the use of self-adherent underwrap assists in the efficacy of white tape at reducing ankle range of motion and should be used especially during the functional and sport-specific rehabilitation phases and when an athlete is returned to participation.

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TABLE 1: Means and standard deviations for Inversion-Eversion Range of Motion (in Degrees)

	Pre-Tape	**Post-Tape**	**Post-Exc**
No tape/control	59.98±3.48	61.20±3.41	62.46±3.13
Tape-Skin	61.19±3.07	40.41±2.01*	46.28±3.28*†
Tape-Foam	61.01±3.19	41.12±2.57*	47.09±2.65*†
Tape-Self-adherent	59.48±3.57	40.19±2.52*	40.78±2.40*

*Significantly different from Pre-tape measure.

†Significantly different from Post-tape measure, indicating loosening.

TABLE 2: Means and standard deviations for Dorsiflexion-Plantarflexion Range of Motion (in degrees)

	Pre-Tape	**Post-Tape**	**Post-Exc**
No tape/control	55.71±2.10	56.11±2.02	57.51±2.04
Tape-Skin	55.89±2.05	42.83±1.70*	46.80±1.91*†
Tape-Foam	54.98±2.06	46.54±1.81*	48.27±1.95*
Tape-Self-adherent	56.36±2.09	42.63±1.54*	42.77±1.53*

*Significantly different from Pre-tape measure.

†Significantly different from Post-tape measure, indicating loosening.

Legend of Figures

FIGURE 1: Electric ankle goniometer

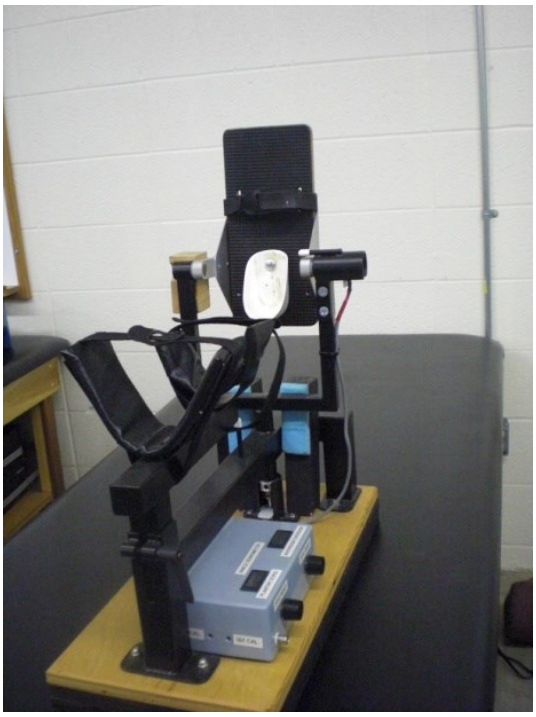


FIGURE 2: Exercise Routine

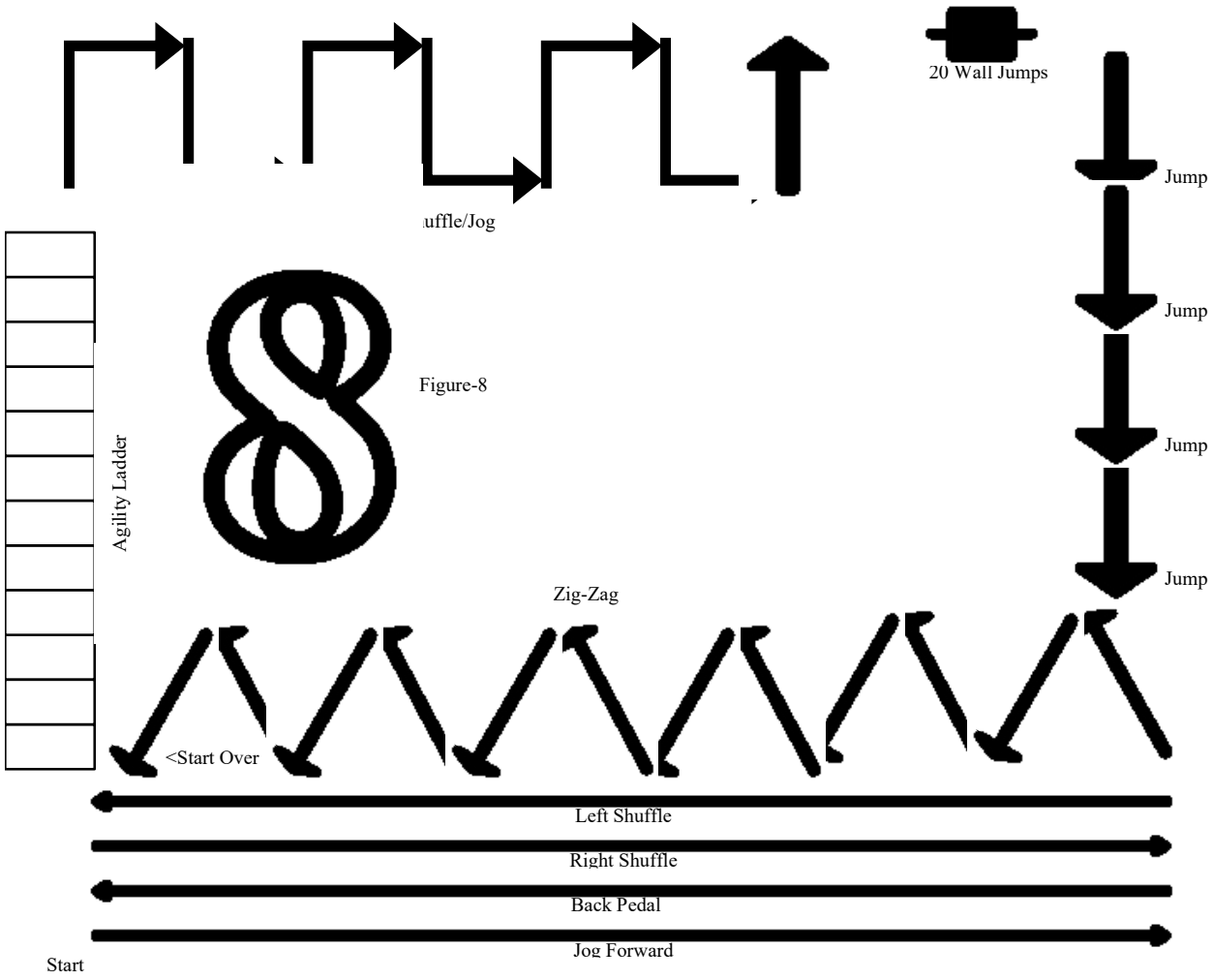
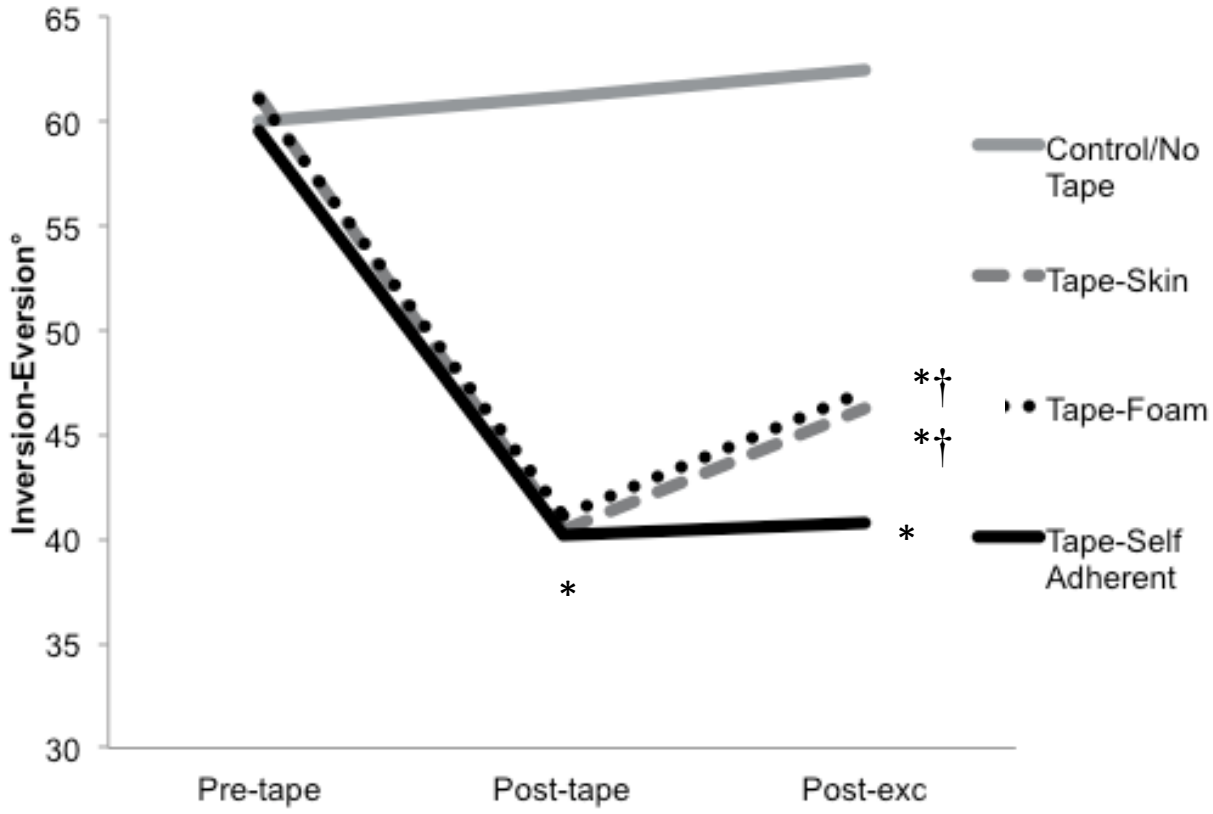


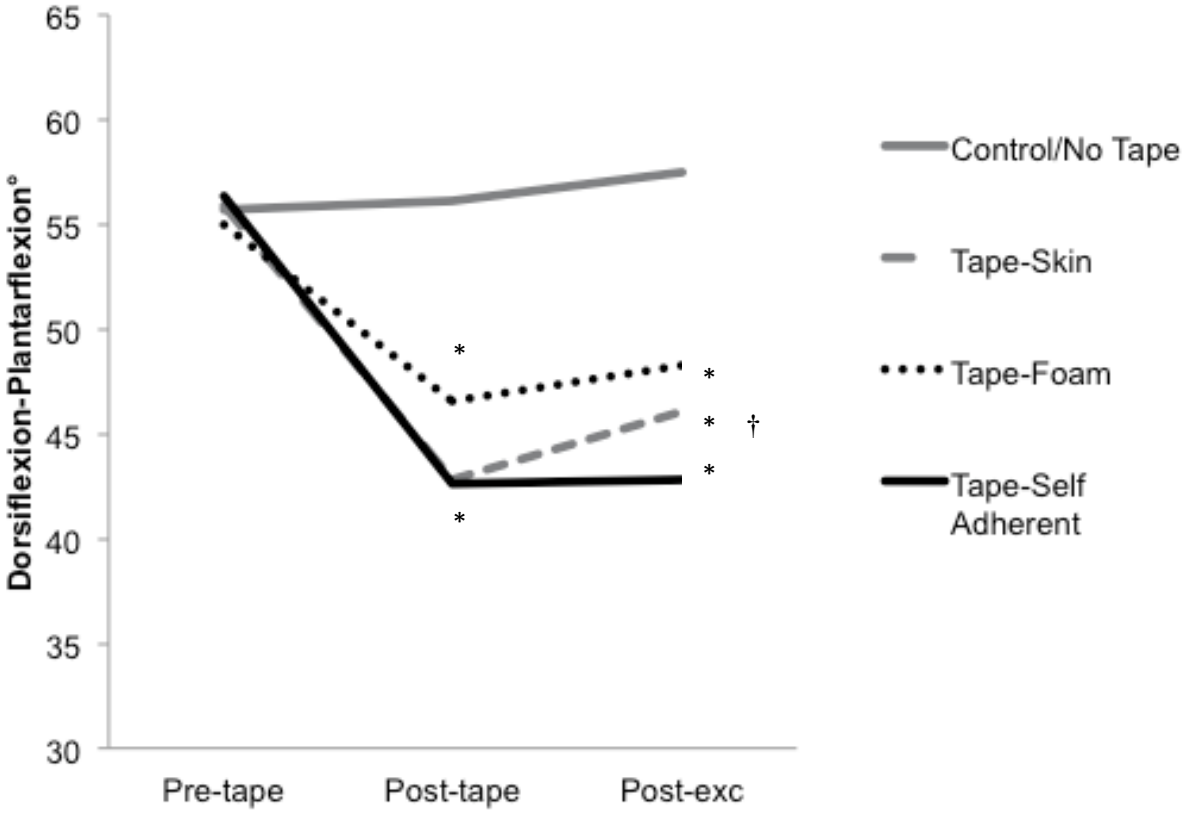
FIGURE 3: Comparison of all taping conditions for inversion-eversion range of motion (in degrees) across the three measurement times



*Significantly different from Pre-tape measure.

†Significantly different from Post-tape measure, indicating loosening.

FIGURE 4: Comparison of all taping conditions for dorsiflexion-plantarflexion range of motion (in degrees) across the three measurement times



*Significantly different from Pre-tape measure.

†Significantly different from Post-tape measure, indicating loosening.

APPENDICES

APPENDIX A

Operational Definitions

For consistency of interpretation the following terms are defined:

Closed basket-weave taping technique: First, the specific underwrap condition was applied per definition described in this section. Using white cloth tape the following was performed: 1) two anchor strips at the base of the calf muscle, 2) one anchor strip around the arch of the foot, 3) three stirrups starting medially and moving laterally, 4) circular strips down the lower leg to cover both malleoli, 5) two heel locks applied to the medial aspect of ankle, 6) two heel locks applied to the lateral aspect of the ankle, 7) figure-8, 8) one anchor strip around the arch of the foot, and 9) circular anchor strips moving up the lower leg.

Dorsiflexion to plantarflexion range of motion: Maximum range of motion at the ankle joint from extreme dorsiflexion to extreme plantarflexion.

Exercise regimen: A thirty minute exercise routine made up of several drills with multi-directional movements including: forward jogging, back-peddling, lateral shuffling to the left and right, a figure-eight, drills with the agility ladder, ten squat-jumps, a "T" drill, forward running with jumping over cones, and a zig-zag jog.[9] Subjects will begin and end with a five minute warm-up and perform the drills at separate stations for a total of twenty minutes.

Fitness levels: Subjects were of varying fitness levels. These levels ranged from physically active (exercises approximately three times per week), to recreational athletes (exercises five or more times per week, often in some sort of team activity).

Foam underwrap: A thin, non-adhesive covering that is applied between the skin and tape. (Mueller®)

Foam underwrap condition: First, adhesive was sprayed over the ankle joint for approximately 3 seconds and allowed to dry for approximately 3 seconds. Then, heel and lace pads were placed on the ankle. Foam underwrap was then be applied starting with a figure-8, followed by medial and lateral heel locks, and finishing in a circular pattern up the lower leg overlapping by half and ending at the base of the calf. The closed basket-weave taping technique was then applied. No white tape was placed on the skin, about 1/8 of an inch of foam underwrap was showing above the first anchor strip.

Healthy subject: A subject with no previous history of lower extremity injury within the previous six months as well as no history of surgery to the lower extremities. Subjects had no history of serious ankle or lower extremity injury. Also, subjects did not have a history of any heart disease or serious medical condition.

Inversion to eversion range of motion: Maximum range of motion at the ankle joint from extreme inversion to extreme eversion.

Self-adherent underwrap: A self-adherent, non-adhesive underwrap that was applied between the skin and tape. (Andover PowerFlex ™)

Self-adherent underwrap condition: First, heel and lace pads were placed on the ankle. PowerFlex™ was then applied starting with a figure-8, followed by medial and lateral heel locks, and finishing in a circular pattern up the lower leg overlapping by half and ending at the base of the calf. When finished, it was compressed to help conform to the ankle joint, per manufacturer's instructions. The closed basket-weave taping technique

was then applied. No white tape was placed on the skin, about 1/8 of an inch of self-adherent underwrap was showing above the first anchor strip.

Spray adhesive: An aerosol adhesive that, when sprayed, leaves a thin coating of adhesive on the skin.

Underwrap or prewrap: A thin covering applied to the skin before the application of tape to aid in reducing skin irritation and friction.

White cloth tape: A 1.5 inch white tape consisting of close cross-sectional fibers with adhesive backing. (Johnson and Johnson Zonas®)

White cloth tape condition: First, adhesive was sprayed over the ankle joint for approximately 3 seconds and allowed to dry for approximately 3 seconds. Heel and lace pads were then applied to the ankle. No form of underwrap was used. The closed basket-weave taping technique was then applied.

Assumptions

The following assumptions applied to this study:

1. Subjects used the same amount of effort with each trial during range of motion testing.
2. Subjects used the same amount of effort each day for the exercise regimen.
3. Thirty minutes of moderate intensity exercise was sufficient to simulate a practice session.
4. Subjects were honest about previous history of lower extremity injuries.
5. Subjects were honest about which is their dominant limb.
6. Subjects represented the normal physically active population.

Delimitations

The following delimitations applied to this study:

1. Only 20 subjects were used.
2. All subjects were between the ages of eighteen and thirty years old.
3. Only the closed basket-weave technique for ankle taping was used.
4. Only one type of white cloth tape was used
5. Only one type of foam underwrap was used.
6. Only one type of self-adherent underwrap was used.
7. All subjects had shaven skin, clear of wounds and lesions, for the ankle being taped.
8. Ankle range of motion was only measured in an open kinetic chain position for both dorsiflexion-plantarflexion and inversion-eversion ranges.
9. An indoor facility with hardwood floors (volleyball court) was the only surface used for the exercise regimen.
10. Between the pre- and post- tests, only thirty minutes of exercise was performed by subjects.
11. All the tape conditions were applied by the same person, the primary investigator.

Limitations

The following limitations applied to this study:

1. Human error accounted for inconsistent tension of tape applied to the ankle for each trial.
2. Specific type of shoe worn was not controlled. Subjects wore their personal, low top, athletic shoes and were instructed to wear the same shoes for each testing day.
3. Tri-planar motion was not measured.

Statement of the Problem

The use of athletic tape to decrease ankle range of motion and aid in the prevention of lateral ankle injuries is widespread and has been extensively researched. Various forms of underwrap are often used when taping to allow for better protection of the underlying skin. A lack of research exists concerning the best method of taping to restrict ankle range of motion, especially when concerning underwrap conditions. Therefore, the purpose of this study was to assess the effectiveness of different underwrap conditions on ankle range of motion before and after exercise.

Independent Variables

Two independent variables were evaluated in this study:

1. Underwrap condition at four levels
    a. No tape, no underwrap (control)
    b. Tape to skin, no underwrap
    c. Tape to foam underwrap
    d. Tape to self-adherent underwrap
2. Time at three levels
    a. Before tape application
    b. Immediately after tape application
    c. Immediately after exercise

Dependent Variables

Two dependent variables were evaluated in this study:

1. Dorsiflexion-Plantarflexion Range of motion (degrees)
2. Inversion-Eversion Range of motion (degrees)

Research Hypotheses

1. There will be a significant difference in the amount of range of motion restriction among the four underwrap conditions.
2. There will be a significant difference in the amount of range of motion restriction before and after exercise.

Statistical Hypothesis

1. $H_A : \mu_C \neq \mu_{TS} \neq \mu_{TF} \neq \mu_{TSA}$
2. $H_A : \mu_{pre} \neq \mu_{post1} \neq \mu_{post2}$

Null Hypothesis

1. $H_0 : \mu_C = \mu_{TS} = \mu_{TF} = \mu_{TSA}$
2. $H_0 : \mu_{pre} = \mu_{post1} = \mu_{post2}$

APPENDIX B

REVIEW OF LITERATURE

Ankle sprains are the most common injury in athletics.[1-9] The majority of these, up to 85%, are lateral ankle injuries.[10] Athletic tape is commonly used to decrease range of motion and aid in the prevention of such injuries.[1, 6, 11-15] Research on this topic is widespread. This literature review will focus on: 1) ankle anatomy, 2) incidence of injury, 3) ankle tape conditions, and 4) the use of athletic tape for ankle injuries, primarily, range of motion restriction before and after exercise.

Review of Ankle Anatomy

Soft tissue ankle anatomy may be broken down into four different areas: anterior, medial, posterior, and lateral.[16] Each region includes several tendons and ligaments all providing for the stability of the ankle mortise as a whole.[10] The anterior portion consists of the tibialis anterior, extensor digitorum longus, extensor hallucis longus and peroneus tertius tendons. The anterior ligament of the leg is named the anterior tibiofibular ligament and is often considered as part of the syndesmosis, the connective tissue located between the tibia and the fibula.[16] The medial aspect of the ankle is made up of the tibialis posterior, flexor digitorum longus, and flexor hallicus longus tendons. The ligamentous components of the medial ankle consist primarily of the deltoid ligament.[16] The posterior area contains the achilles tendon along with the posterior tibiofibular ligament, also associated with the syndesmosis. The lateral portion of the ankle contains the most relevant elements for discussion of ankle anatomy. Tendons of the lateral aspect include the peroneus longus and brevis tendons; ligaments include the anterior talofibular, posterior talofibular, and calcaneofibular ligaments.[16]

Location of the muscle typically determines the primary action it has on ankle range of motion. The muscles associated with each tendon act to move the ankle through varying degrees

of motion. The anterior tendons and muscles are primarily responsible for dorsiflexion, the medial for inversion, the posterior for plantarflexion, and the lateral for eversion.[10, 16] The tendons and their associated muscles provide dynamic stability to the ankle joint. All ligaments of the ankle allow for static stability of the ankle joint.

Incidence of Injury/Etiology

As previously stated, research has shown ankle injuries to be one of the most common injuries especially with those individuals participating in athletics. [1-7, 11, 12, 14, 17] For example, one study investigated 100 high schools during the 2005-2006 school year.[18] The schools' reported over 300,000 ankle injuries, accounting for almost one quarter of all the injuries sustained that year.[18] This study also found athletes who participated in sports involving sudden changes of direction and greater degrees of cutting suffered ankle injuries more frequently.[18] Of these injuries, sprains were the most common.[18] An investigation of the injuries reported during the 2004 Olympics discovered that out of all foot and ankle injuries, ankle sprains were the second most common.[17] A primary concern with ankle sprains is the increased likelihood of chronic instability[10] as well as re-injury.[6]

Of all ankle injuries, lateral ankle sprains are the most common.[1, 2, 4-8, 10, 11, 19, 20] Lateral ankle sprains typically result from an excessive inversion, plantarflexion, and internal rotation force[2, 5, 21] causing one or more of the lateral ligaments to partially tear or rupture completely.[2, 5] One study found that with increasing amounts of plantarflexion the likelihood and severity of an ankle sprain also increases.[22] The cause behind this excessive force varies by the type of injury. It can come from irregular surfaces, stepping on equipment, stepping on another athlete, or a quick change of direction.[2] Ankle sprains are commonly graded based upon the amount of

ligamentous damage. A grade one sprain will have the least amount of damage and may involve only a partial tear to one ligament while a grade three sprain could involve complete ruptures of multiple ligaments. The anterior talofibular ligament is placed under the most stress during plantar flexion and internal rotation while the calcaneofibular ligament is stressed the greatest with dorsiflexion and inversion motions.[21] The anterior talofibular ligament is the smallest, and thus the weakest, of the lateral ankle ligaments making it the most commonly injured.[5]

Ankle Tape Conditions

Over the years several taping techniques have been used to prevent ankle sprains, stabilize the joint, and decrease swelling following an injury.[6] The subtalar sling and the closed basket-weave techniques are among the most discussed in the literature. The subtalar sling has been discussed in several studies as a method of ankle taping.[4, 5, 23] The goal of the subtalar sling taping technique is to limit the amount of varus stress and displacement of the hindfoot resulting in a decreased chance of an inversion ankle injury.[5] Proper application is fundamental for function of the subtalar sling technique. An anteriorly placed sling allows for greater range of motion restriction but less comfort while a posteriorly placed sling does the opposite.[23] However, the majority of research concerning ankle taping uses the closed basket-weave technique, or a modification of it.[7, 13, 14, 19, 23-36] Thus, for the purpose of this study the closed basket-weave technique will be discussed in greater detail.

Before the application of tape, skin should be clear of any sort of wound.[6] Outside of this recommendation, skin preparation before application of tape varies depending on the goals of the study. Most studies incorporate the use of heel and lace pads[4, 13, 30, 32, 34, 35] for the prevention of blisters where the tendons are superficial and could cause excess friction due to the tape. Some studies also use spray adhesive on the skin[4, 13, 14, 25, 26, 30, 32] to allow for a better hold of the tape.

Underwrap is also commonly used for ankle taping and will be discussed in detail later in this section.

After skin has been prepped the ankle is ready to be taped. The closed basket-weave technique can, and has been, modified by clinicians and researchers to meet their specific needs. However, each closed basket-weave taping typically consists of the same parts: anchor strips, stirrups, horseshoes, figure-eights, and heel locks.[37-40] The modifications are based on the order in which the parts are applied as well as the number of each part applied to the ankle. Each component plays a role in limiting ankle range of motion and providing greater stability to the ankle joint.[39] Two studies have investigated the individual components of the different methods used for ankle taping, concluding the basket-weave with two heel locks was the most effective at restricting range of motion.[38, 40]

Underwrap Conditions

Underwrap has been used for years during ankle taping to aid in reducing friction and lessening skin irritation.[4, 6, 9, 13, 14, 19, 25, 26, 29, 30, 32, 34] In the past gauze was used as a form of underwrap[25] but over the years a foam underwrap, or prewrap, has become the popular choice.[4, 9, 13, 14, 19, 25, 26, 30, 32, 34, 35, 41] Recently, a self-adherent prewrap has been developed as yet another form of underwrap. Purcell et al.[34] discuss the use of self-adherent prewrap as a possible contributor in maintaining range of motion restriction for an ankle taping. The study reports self-adherent prewrap has additional tensile strength and moisture restraint capabilities not found in other forms of underwrap.[34]

Few studies examine the use and effect of different forms of underwrap during ankle taping.[25, 26, 29, 30, 35] These studies investigating underwrap conditions have contradictory

findings. One study reported the use of underwrap facilitated range of motion restriction[25] while others concluded underwrap decreased range of motion restriction[26, 29] compared to tape to skin conditions. Furthermore, other investigators found no difference in range of motion restriction when using underwrap compared to tape to skin methods.[35]

Delacerda[25] investigated the differences between tape to skin, tape to gauze, and tape to foam underwrap both before and after exercise, discovering that when using gauze or foam underwrap subjects exhibited greater range of motion restriction compared to no underwrap.[25] They found in tape to skin conditions that the tape usually tore and loosened excessively, thus tape to skin did not maintain its' restrictiveness as well as the tape to underwrap conditions.[25] No significant difference was found when comparing the gauze to foam underwrap.[25] Another study investigated the effects of adhesive spray and prewrap on ankle inversion,[26] and came to an opposite conclusion. They found that tape to skin with adhesive spray resulted in the most range of motion restriction both before and after exercise.[26] The tape condition with prewrap and no adhesive spray was the least effective in limiting ankle inversion.[26] Another study compared the use of stockingette as underwrap to two other conditions, tape tso skin and the Louisiana wrap (cloth wrap over a sock with a tape heel lock).[29] This study also concluded tape to skin was the best method for restricting ankle range of motion.[29]

Another study compared tape to skin versus tape to foam prewrap both before and after exercise.[35] They measured several variables including inversion range of motion, time to maximum inversion, average inversion velocity and maximum inversion velocity.[35] The authors concluded that both tape to skin and tape to prewrap were equivalent to one another for each variable.[35] Both tape conditions were able to limit inversion range of motion, decrease average and maximum inversion velocity, and decrease maximum time to inversion both before and after

exercise compared to the no tape condition.[35] Finally, another study[30] also found no difference between tape to skin versus tape to prewrap, but instead of measuring range of motion restriction they evaluated active and passive ankle resistance to inversion.

These few investigations involving the comparison of underwrap conditions did however reach one consensus. All found that no matter what type of underwrap condition its' restrictive capabilities are lessened with exercise.[25, 26, 29, 30, 35] Many investigators examine the effects of exercise on ankle taping and range of motion restriction report the use of a foam underwrap but fail to elaborate further on its role in the ankle taping.[4, 9, 13, 14, 19, 32, 34]

Use of Ankle Tape

The use of athletic tape for the prevention of ankle injuries has been popular for many years in athletics. Athletic tape has been shown to be effective in reducing the number and severity of ankle sprains.[13, 25] One study reported that with ankles taped for all sports activities the chance of an ankle sprain decreased by at least 50%.[37] Karlsson et al.[6] stated that tape was thought to be effective for three primary reasons. The first was by decreasing mechanical ankle instability, the second by limiting the extremes of ankle motion, and the third by improving proprioceptive ability.[6] One study interviewed athletes to determine the reasoning behind getting their ankles taped. The athletes reported they did so either because they felt tape increased confidence, increased strength or decreased concern for injury/re-injury.[42] For the purpose of this study only the use of tape for range of motion restriction will be discussed in detail.

Research conducted over the past sixty years has shown the use of athletic tape significantly decreases ankle range of motion immediately after its' application.[1, 3, 4, 6, 7, 9, 11-15, 24-26, 29, 32-36, 43, 44] Studies measured ankle range of motion first, with no external support, then after

the initial application. The amount of restricted ankle movement varied among studies and also

Joint Motion	Range of Motion (Degrees)

depended upon the range of motion measured. Most researchers suggest the greatest plane of motion limited with taping was inversion and plantarflexion.[1, 3, 4, 6, 9, 11, 13, 31, 32, 34, 35, 44] However, dorsiflexion, eversion, internal rotation and supination have all been reported to be restricted as well.[7, 15, 24-27, 29, 30, 33, 35, 36, 38, 40] Measurement methods for ankle range of motion varied amongst the studies. Studies have also added exercise elements where ankle motion was measured pre and post exercise to determine the effect exercise may have had on the restrictive properties of ankle taping.[1, 3, 4, 7, 9, 11-13, 24-26, 28-31, 33-36, 44]

In theory, tape application to the ankle acts as an external support to the ankle ligamentous structures.[7] The tape restricts excessive joint range of motion, providing for increased stability at the ankle joint. Two studies have found that with increased plantarflexion the chance and severity of an ankle sprain increases, especially if the individual has a previous history of ankle injury.[22, 41] They also determine that taping limits plantarflexion and thus the risk of injury decreases with ankle taping.[22, 41] In order to identify if ankle motion is being limited by tape one must first know the normal ranges of motion (Table 1). Ranges are given rather than specific degrees of motion because each individual will differ based on ankle biomechanics, as well as the method of measurement. The best system for determining normal range of motion for an individual is to compare bilaterally.[39, 45]

Dorsiflexion	10-30
Plantarflexion	45-65
Inversion	30-52
Eversion	15-30

Table 1. Ranges of normal ankle motion.[46-51]

Range of motion restriction- Immediately after application

A study published in 2009 found tape to decrease ankle inversion by 62% immediately after tape application.[11] A study released ten years earlier also reported similar findings,

showing a 48-50% decrease in inversion and a 62-63% decrease in plantarflexion immediately after tape application.[28] The differences in percentage depended upon the type of tape used.[28] Furthermore, a meta-analysis was performed on nineteen different studies to determine the efficacy of tape, semirigid bracing, and lace-up bracing on limiting ankle range of motion found all three conditions to significantly limit inversion range of motion after application.[1] One study took x-rays to measure talar tilt in subjects before and after tape application.[36] They determined that on average, tape caused talar tilt to decrease from 13.4 degrees to 4.9 degrees after application.[36] Research is inconsistent on the degree of motion limited by tape after application. While most studies found a large decrease of up to 35 degrees of plantarflexion[3], others reported small decreases as low as 10 degrees of plantarflexion.[33]

Range of motion restriction- After exercise

The majority of studies used white cloth athletic tape for pre to post exercise investigations.[4, 11-13, 26, 29-33, 35, 36, 44, 52] Few studies have used other types of tape.[15, 24, 28] Studies measuring range of motion of the taped ankle after exercise all varied on the amount of time the subject exercised before range of motion was measured again. One study measured after ten minutes of exercise[4] while another measured after two hours.[25] Many studies also measured at time intervals throughout an exercise regimen.[3, 11, 14, 29, 33, 44] The exercise routines incorporated by various studies differed slightly but most involved some sort of running drill, change of direction drills, and lateral movement drills. Figure eights, ladder drills, and other agility maneuvers were often used.[7, 26, 31, 34, 35] Furthermore, studies have used treadmills,[31, 44] assorted jumping maneuvers,[3, 53] sprints[27, 52, 53], and sport practices[25, 33] as their exercise protocols. Typically the protocols consist of a combination of different drills and exercises.

Many factors play a role in the ability of tape to restrict range of motion after exercise. Type of tape, exact location and amount of tension for each specific strip, amount of the adherence, and use of underwrap may all contribute.[23] Another possible contributor to reduced range of motion restriction after exercise has been attributed to increased tissue pliability.[35] Due to the warm-up effect exercise has on soft tissue, an increase in joint mobility has been noticed when post baseline measures are taken.[33, 35]

In studies where range of motion was measured at different time intervals, all found that tape loosens the most within the first minutes of exercise and typically continues to loosen with more exercise.[14, 29] A meta-analysis of nineteen different studies found a consensus among each study; all investigations reported similar results, showing tape loosened with exercise.[1] One study reported an average loss of support of 30 percent for each condition tested, following exercise.[26] The conditions consisted of different combinations of tape, underwrap, and adhesive spray.[26] Another investigation found that after twenty minutes of exercise inversion range of motion increased by 14-15 degrees (64-65% of the baseline measure) and plantarflexion increased by 46-50 degrees (87-96% of the baseline measure).[28] One study used x-ray to measure talar tilt with ankles taped versus untapped both before and after exercise.[36] They found that after exercise talar tilt had increased by an average of 2.0 degrees compared to pre-exercise measures.[36] Another study involved the use of self-adherent tape and prewrap compared to the typical white tape and foam prewrap.[34] They found the self-adherent condition loosened with exercise but not to the same degree as the white tape condition.[34]

Most investigations have concluded that tape loosens with exercise and limits range of motion more immediately after application.[1, 3, 4, 7, 9, 12-14, 24-26, 29-35, 44, 52] Researchers disagree whether or not tape still provides sufficient protective range of motion restriction after loosening

due to exercise. Most studies suggest that even with decreased range of motion restriction after exercise, tape still limits excessive ankle motion, sufficient to prevent an ankle injury or re-injury.[1, 3, 7, 9, 13-15, 26, 28, 35, 41] Conversely, some studies have determined that the loss of restriction due to exercise renders the tape useless for limiting range of motion.[25, 33] One study measured ankle motion before exercise, after twenty minutes of exercise and after one hour of exercise.[33] They found that after twenty minutes of exercise the tape was still able to provide some range of motion restriction, but after one hour the tape's supportive effects were not sufficient to significantly decrease the chance of injury or re-injury.[33]

Conclusion

Ankle sprains are among the most common injuries occurring in athletics. [1-7, 11, 12, 14, 17] Ankle taping is an effective means of preventing these injuries, typically by reducing the severity and incidence of ankle sprains.[13, 25] Variations exist among the techniques and materials used by athletic trainers and clinicians to tape ankles. The closed basket-weave technique is the most commonly used in research. [7, 13, 14, 19, 23-36] Few studies have investigated the effects of underwrap on ankle taping and the results vary among the studies.[25, 26, 29, 30, 35] Many studies have investigated the effects of ankle taping on range of motion restriction.[1, 3, 4, 6, 7, 9, 11-15, 24-26, 29, 32-36, 43, 44] The results of these investigations typically found tape significantly restricted ankle range of motion immediately after application[1, 3, 4, 6, 7, 9, 11-15, 24-26, 29, 32-36, 43, 44] but loosened with exercise causing a decrease in its restrictive ability. [1, 3, 4, 7, 9, 12-14, 24-26, 29-35, 44, 52]

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